Northumbria University NEWCASTLE

Newcastle University

An evaluation of dust release when machining nano-structured composite materials

Islam Shyha, Michael E. Deary, Dehong Huo

Alexandria, 11-13 March 2018

About me

- Educated in Egypt
- PhD from Birmingham, UK
- Work in Newcastle, UK

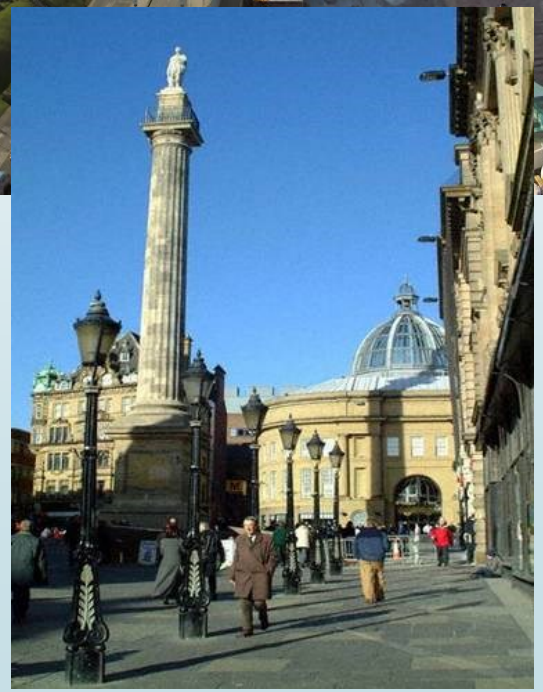




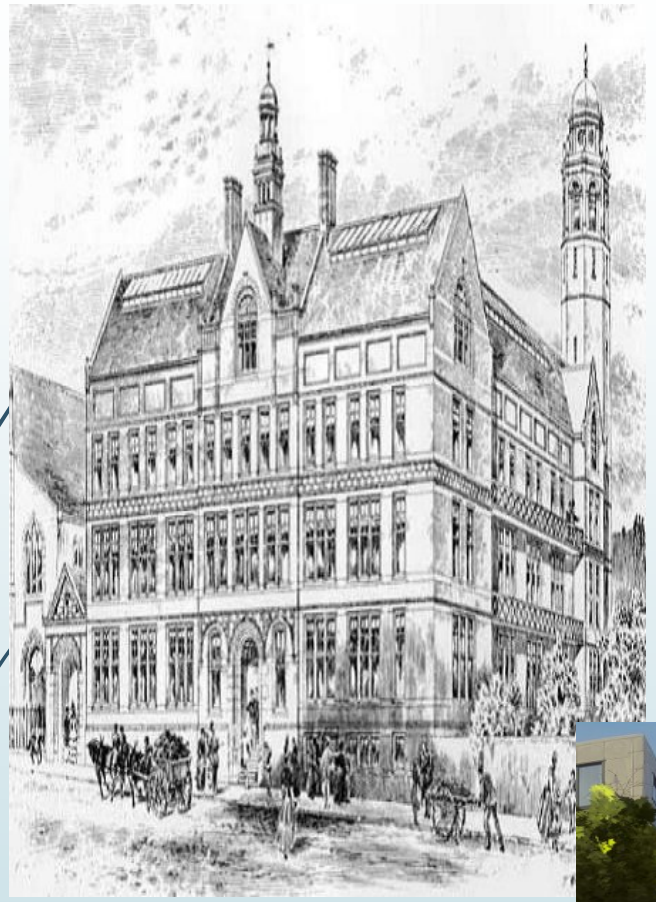

Newcastle upon Tyne

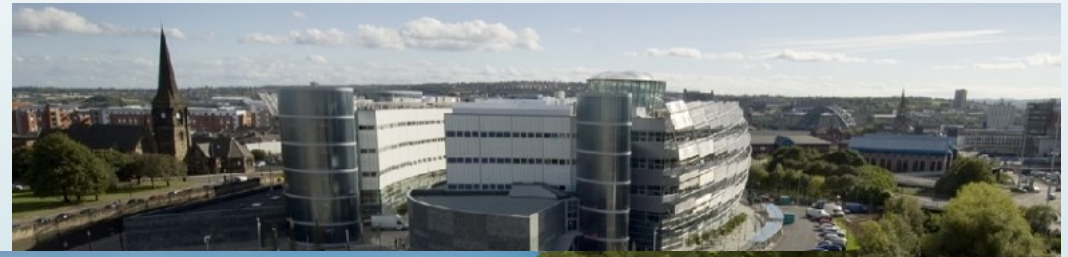
- Capital of England's North East
- Rich in history and culture
- Britain's "Best University City"

Newcastle upon Tyne



Northumbria University





An evaluation of dust release when machining nano-structured composite materials

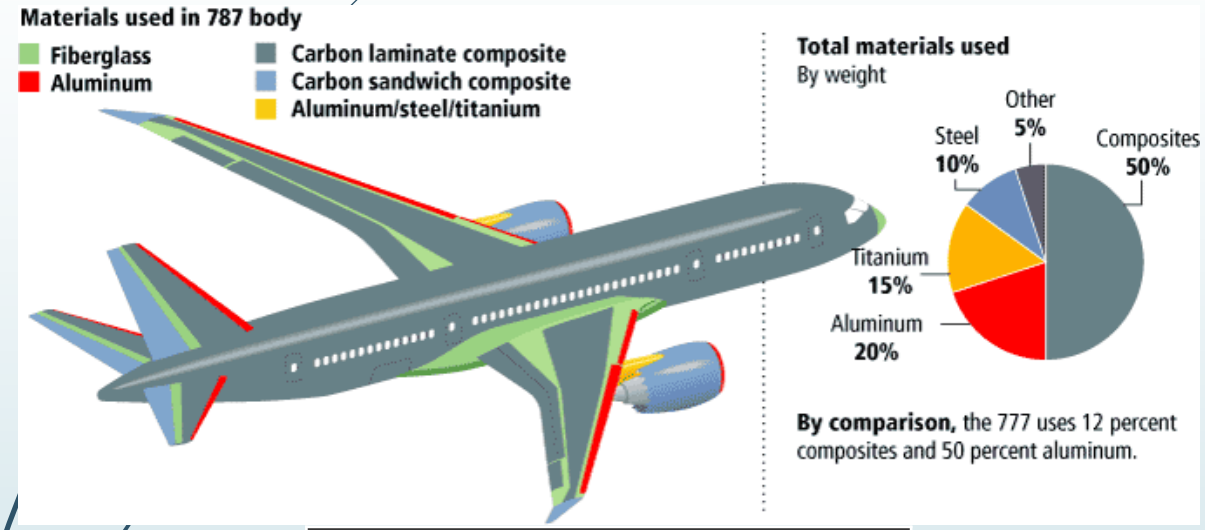
Outline

- Introduction
- Nanocomposite Safety
- Experimental Work
- Analysis of Results
- Conclusions and Future Work

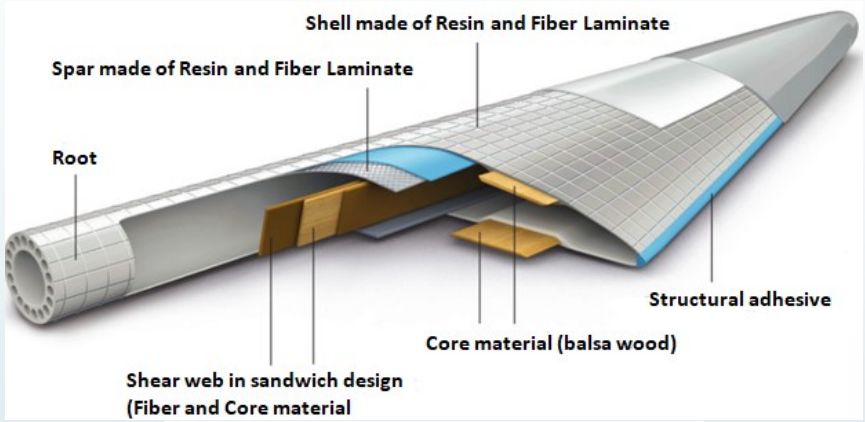
Introduction

- Machining produces dust (heavy chips rest on machine beds while finer particulates become airborne)
- Why dry micromachining is chosen: likely to produce the smallest particulates
- Nano-composites are more hazardous due to the risk of generating/releasing nano-particulates

Composite materials

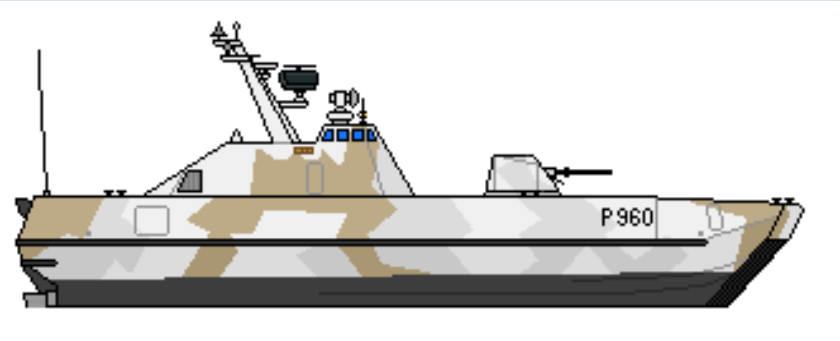


(Source: Modern Airliner)



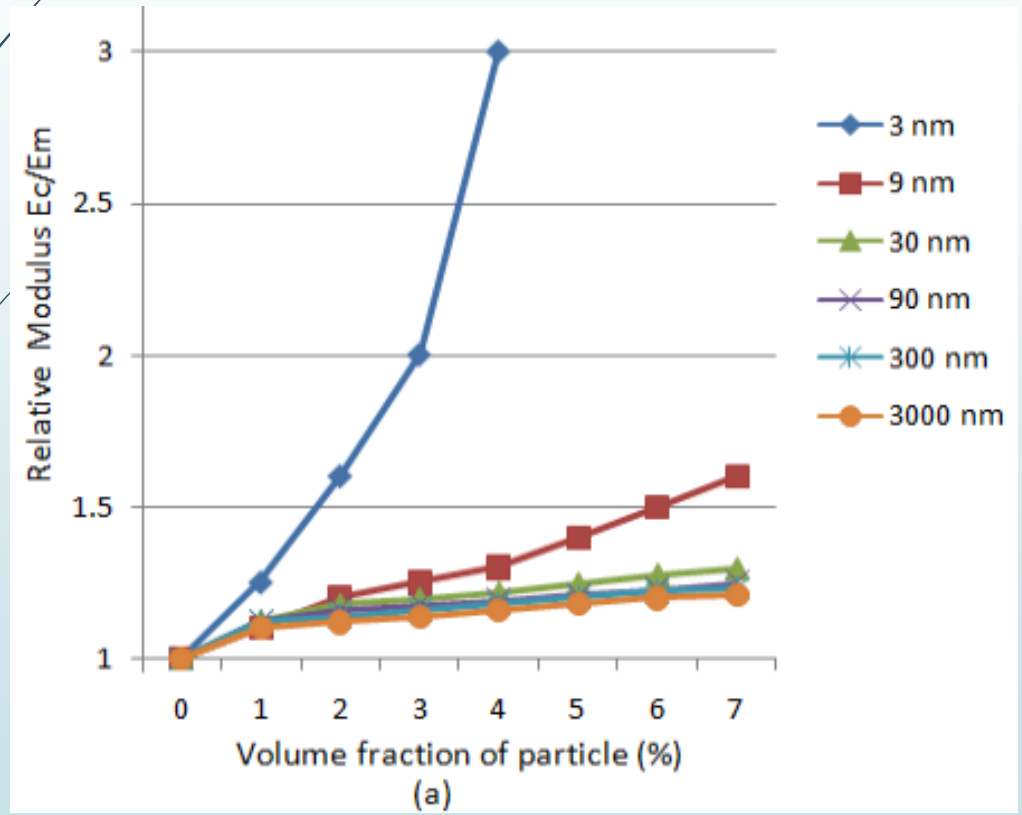
(Source: 3D printing Industry)

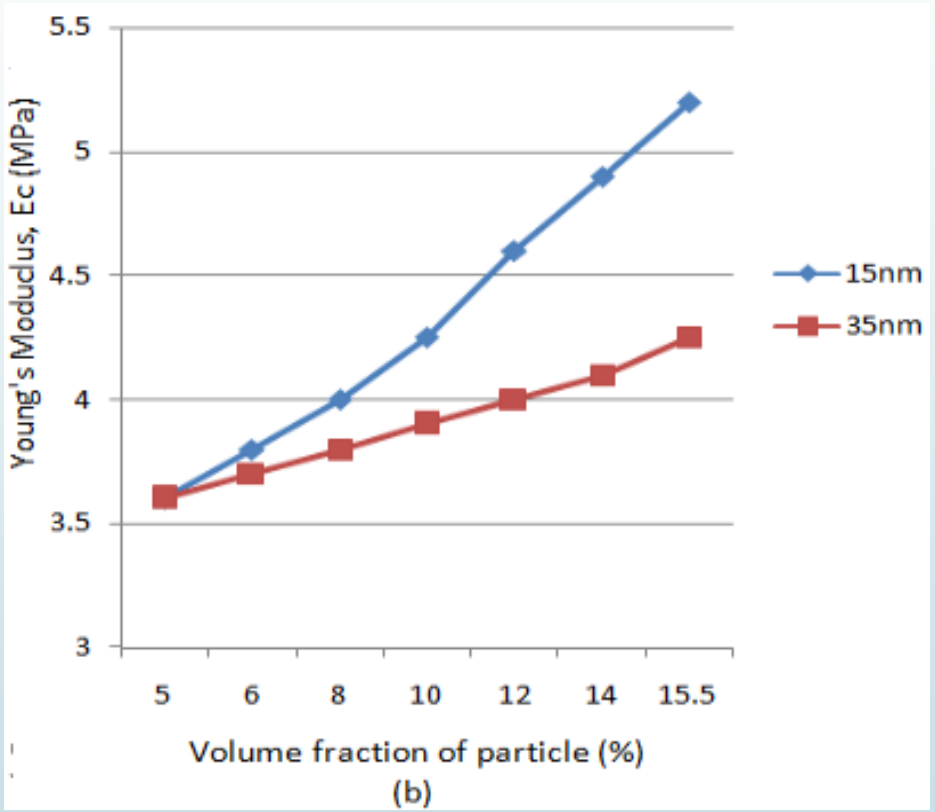
(Source: Otto Bock Health Care)



(Source: Navy Recognition)

Potential of Nanocomposites





Modulus vs particle size in nano-scale: (a) nylon6/montmorillonite, (b) Polysiloxane/SiO_2

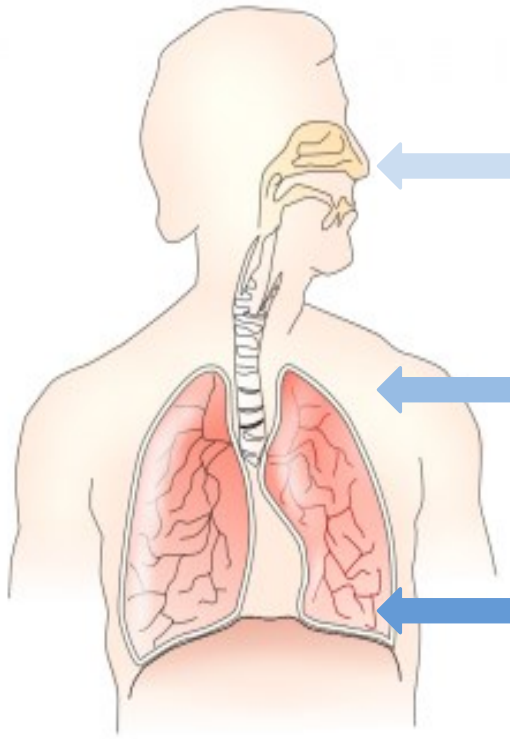
Ji, X.L., et al., *Tensile modulus of polymer nanocomposites.* Polymer Engineering & Science, 2002. **42**(5): p. 983-993.
Douce, J., et al., *Effect of filler size and surface condition of nano-sized silica particles in polysiloxane coatings.* Thin Solid Films, 2004. **466**(1): p. 114-122.

Why dry machining

- The use of cutting fluids can:
  - have a high adverse impact on human health and ecosystem
  - have an expensive disposal & waste management costs (low rate of biodegradability 20 -30%)
  - high consumption rate (EU alone consumes approximately 320,000 tonnes of CFs/year)
- There is a need for dry machining:
  - Machine tool capabilities
  - Potential chemical interaction between cutting fluid and workpiece

Compressed air/vapour/gas

Dust Inhalation in the Workshop Environment



Dust Inhalation in the Workshop Environment

Inhalable dust (< 100 μm*): fraction of a dust cloud that is inhaled into the nose and mouth
UK WEL for inhalable dust: 10 mg/m³ 8-hr TWA
IOM recommended WEL: 5 mg/m³ 8-hr TWA**

Thoracic dust (< 10 μm*): dust that penetrates beyond the head airways and enters the airways of the lungs

Respirable dust (< 4 μm*): dust that can penetrate deeply into the lungs beyond the gas exchange region
UK WEL for respirable dust: 4 mg/m³ 8-hr TWA
IOM recommended WEL: 1 mg/m³ 8-hr TWA**

* BS EN 481:1993 Workplace Atmospheres.
**Since 2011, the Institute for Occupational Medicine (IOM) has stated the current UK legal limits for inhalable and respirable dusts are too high to protect worker health. The IOM recommendations can be taken as best practice.

Nanocomposite Safety

- Throughout their lifecycle nanocomposites will undergo machining: safety concerns relate to the rate and volume of nanomaterial release from the matrix
- Research into nanomaterial safety has expanded alongside their use in research and industry but few studies focus on the release of nanomaterials from nanocomposites
- Lack of studies into nanomaterial release from nanocomposites makes rigorous risk assessment and management of occupational exposure impossible
- Available studies do show release of nanomaterials from the composite matrix during a variety of machining activities

Froggett et al. Particle and Fibre Toxicology 2014

Occupational Exposure to Nanomaterials: Safety Limits

- There are no specific exposure limits for nanomaterials
- UK WELs found on Safety Data Sheets for nanomaterials are either:
  - Those listed for inhalable and respirable dusts: 10 mg/m^3 8-hr TWA and 4 mg/m^3 8-hr TWA respectively
  - Those listed for the parent material e.g. halloysite nanoclay: 2 mg/m^3 8-hr TWA, graphene: 2 mg/m^3 8-hr TWA

Research Aims

- quantitatively assess the particulates released when machining nano structured composites.
- study the effect of distance and operating conditions on particulate distribution.

Experimental work

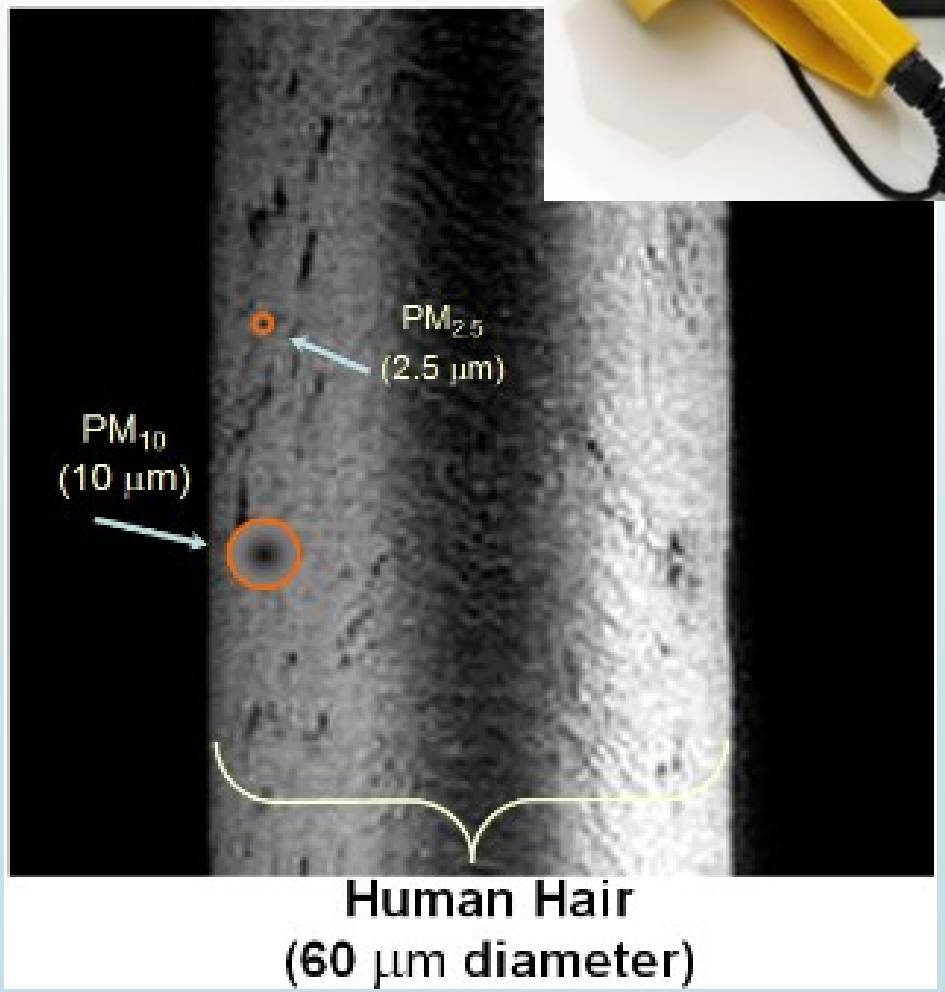
- Two 0.5% filler nanocomposite materials (graphene/epoxy & halloysite nanoclay/polyester) were micro slotted.
- Using 1 mm diameter carbide end mills under various cutting conditions.
- Machine tool: Nanowave MTS5R micro milling machine.

Variable/Level	1	2	3	4
Workpiece material	Graphene/epoxy	Nano-clay/polyester		
Cutting Speed (m/min)	31.4 (10,000 rpm)	94.2 (30,0000 rpm)	157 (50,0000 rpm)	
Feed rate (μm/rev)	5	15	25	
Depth of cut (μm)	50	100	150	
Location of Dustmate (cm)	10	30	50	100

Experimental setup: particulate monitor is at 10 cm away from the machining zone

Experimental Work

- A portable particulate monitor was used at different locations away from the machining zone (tool tip).
- Measured the released PM_{10}, $PM_{2.5}$, PM_1 concentrations.
- Workplace Exposure Limit: UK EH40.
- One average concentration reading per second.

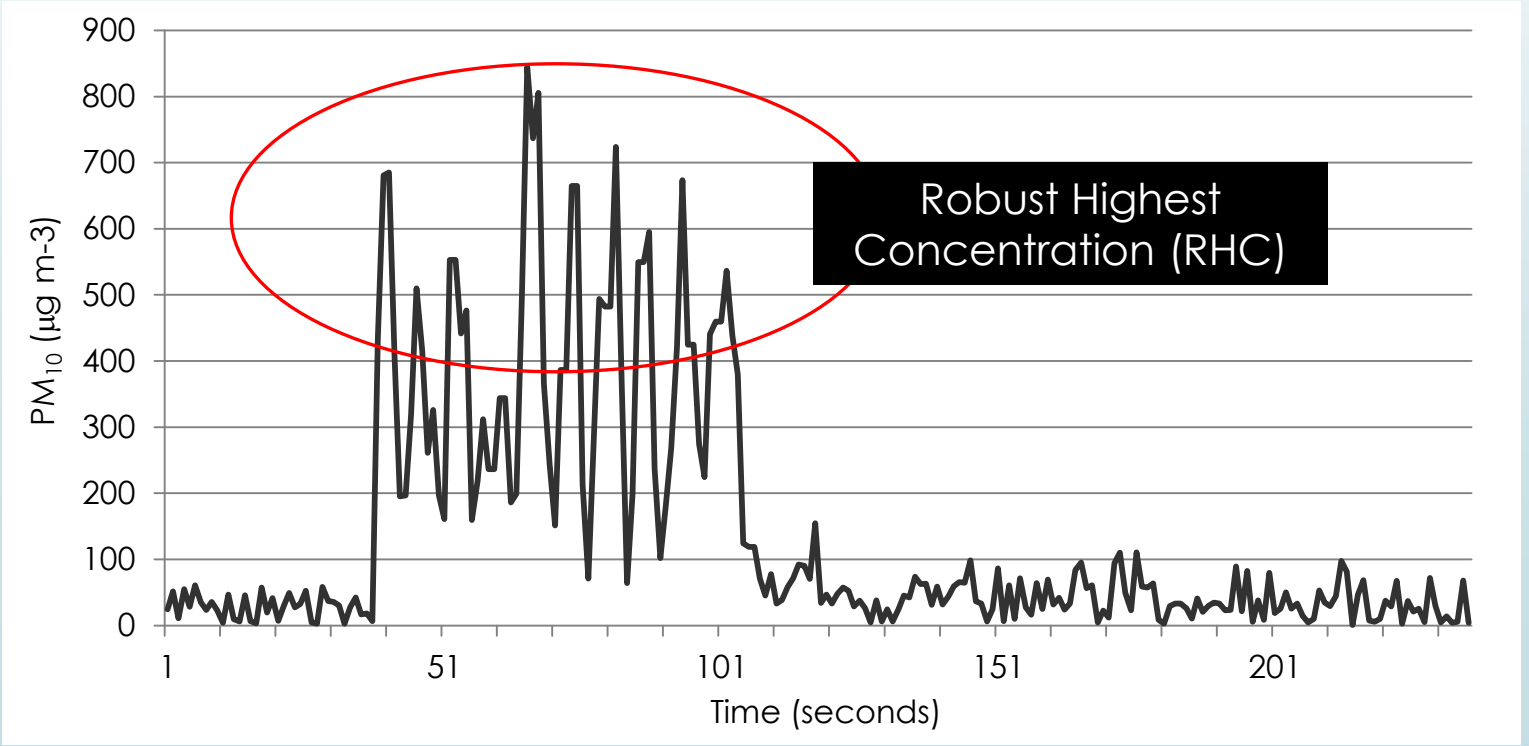


Analysis of results

- Robust Highest Concentration (RHC) was calculated: this is a statistical parameter used in ambient air quality studies (worst case parameter).

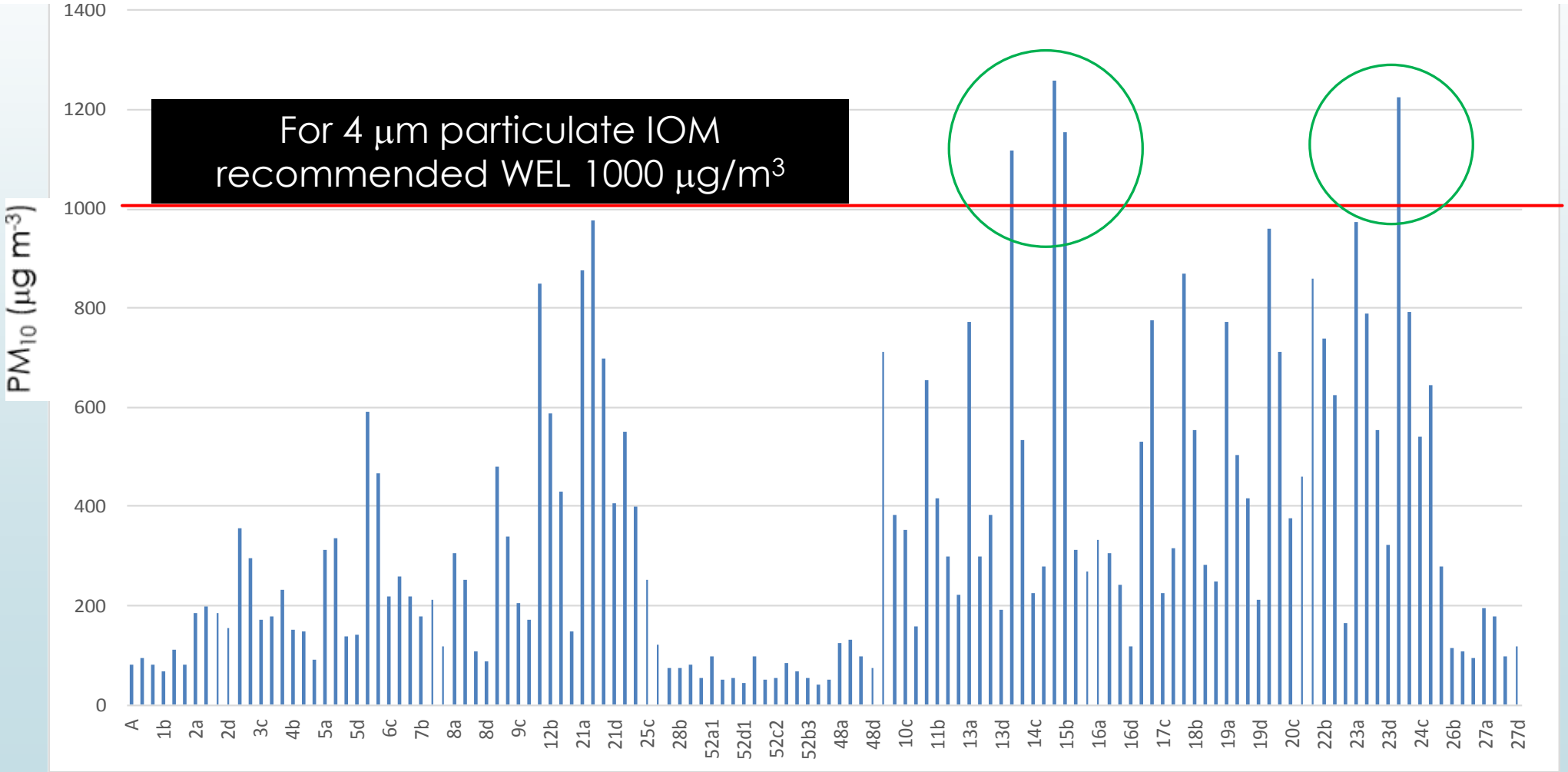
$$RHC = X_n + (\overline{X}_{n-1} - X_n)\ln\left(\frac{(3n-1)}{2}\right)$$

Profile of PM_{10} concentration:
graphene/epoxy, 94.2 m/min, 5 μm/rev, 150 μm, 30 cm distance



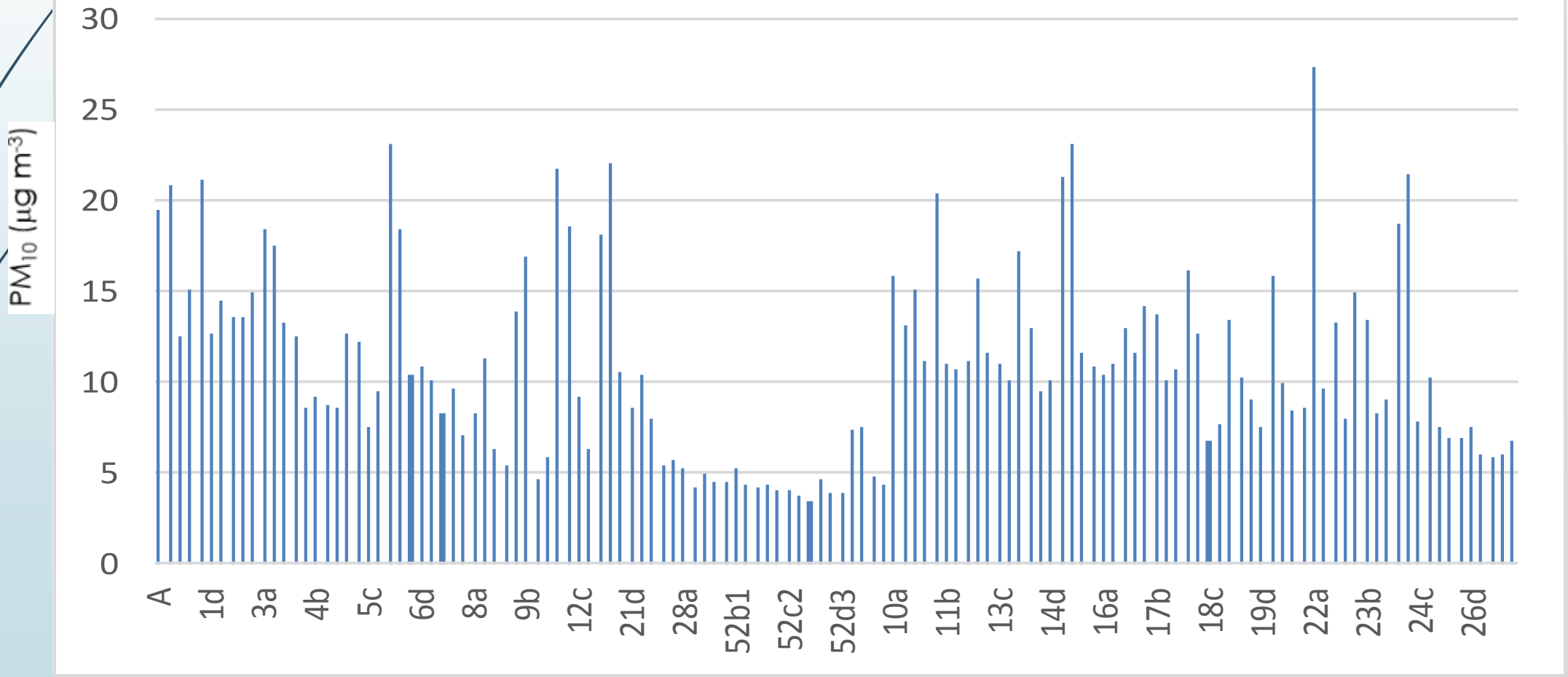
RHC of PM_{10} (µg m^{-3})

UK EH40 WEL for respirable dust (<4µm) is 4,000 µg m^{-3}, well above all of the experimental conditions tested but few trials exceeded the IOM recommended limits.



RHC of $PM_{2.5}$ (µg m^{-3})

UK EH40 Workplace Exposure Limit (WEL) for respirable dust (<4µm) is 4,000 µg m^{-3}, clearly well above all of the experimental conditions tested



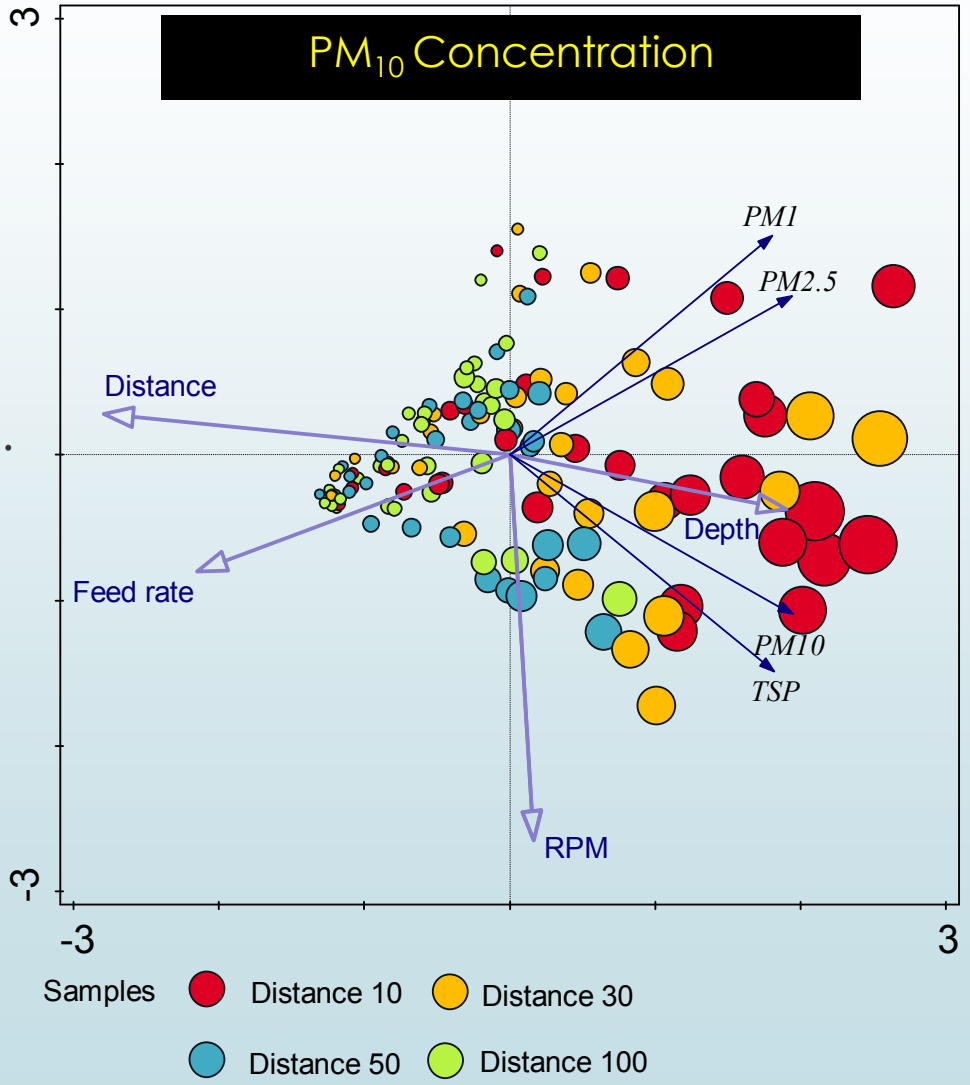
Observations

- The key point with nanomaterials is the applicability of the precautionary principle.
- It doesn't mean coming in under the available WELs, it is ok to machine nanocomposites with no extraction.
- Therefore, this work draws attention to the need for WELs for nanomaterials and output from nanocomposites because current legal limits applied could really lull people into a false sense of security.

Results: Principal Component Analysis (PCA)

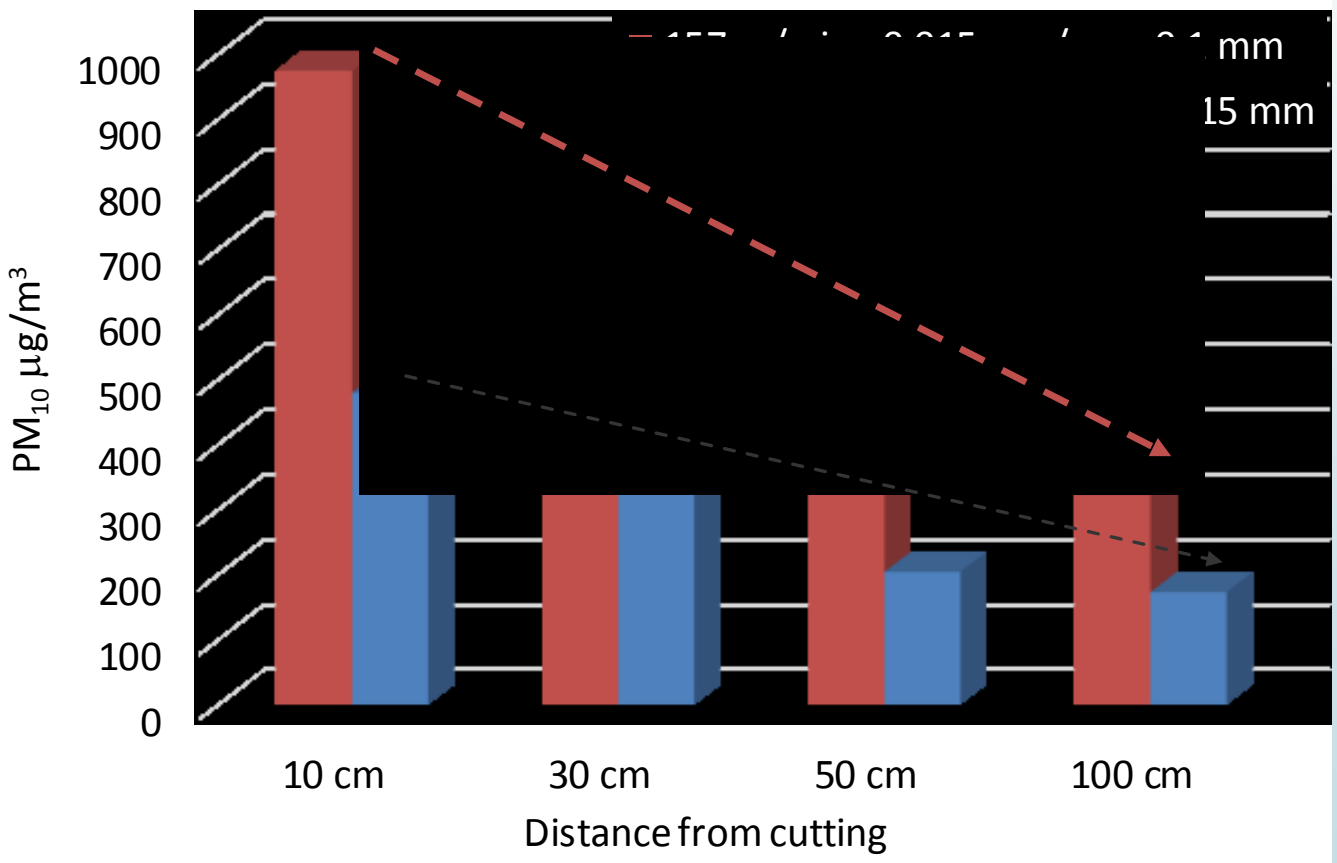
- PCA used to determine the relationships between concentrations and the factors.

- Size of circle is proportional to PM_{10} concentration.
- Colours indicate distance categories.
- Closely aligned arrows indicate positive correlations (e.g. PM_{10} with depth of cut)
- Oppositely aligned arrows indicate negative correlation, e.g. PM_{10} and distance
- PM_1 and $PM_{2.5}$ not closely aligned with PM_{10}, therefore not strongly correlated.
- Orange and red circles (closer distances), clearly associated with highest concentrations.



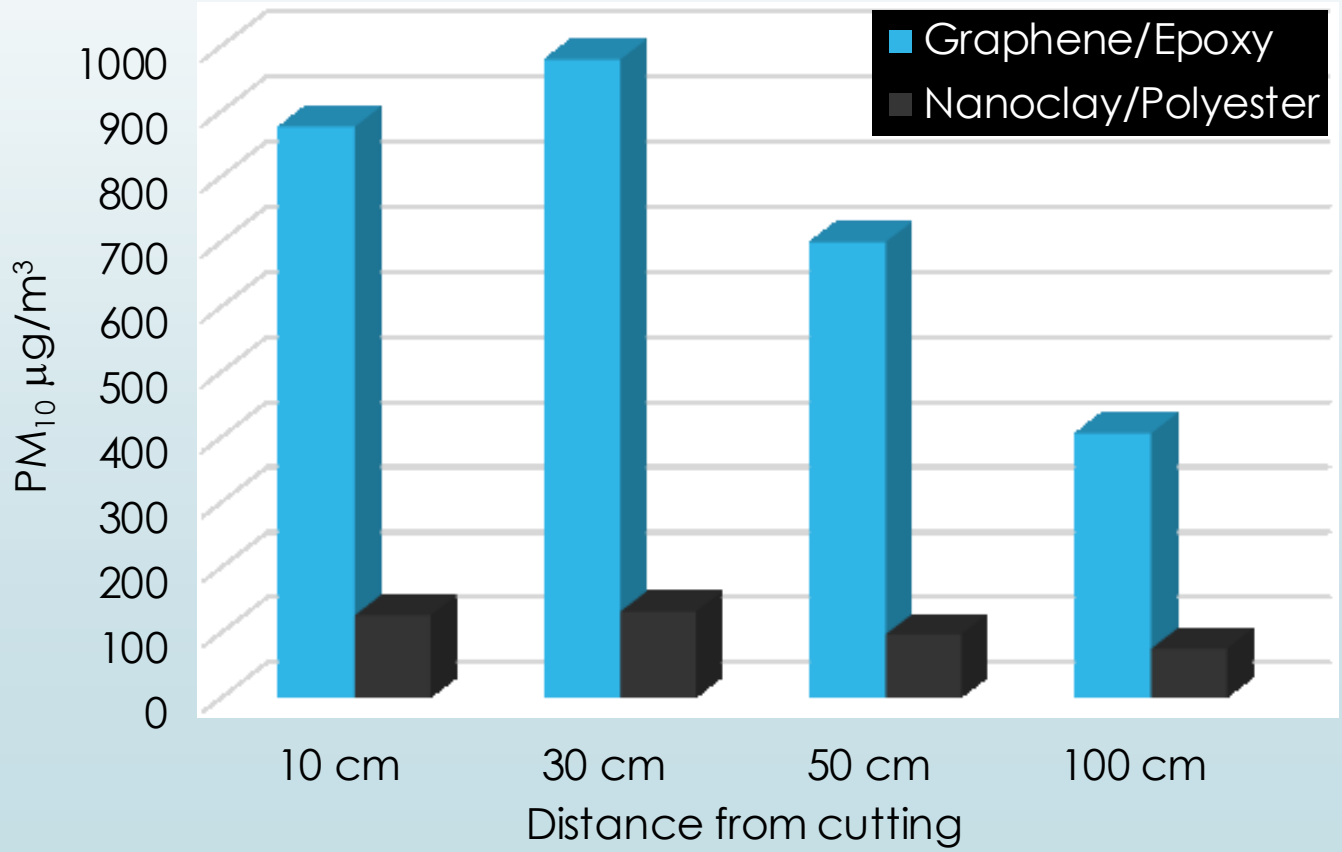
Effect of distance on PM_{10} concentration

- Peak of particulates concentration at 10 cm away from the tool tip



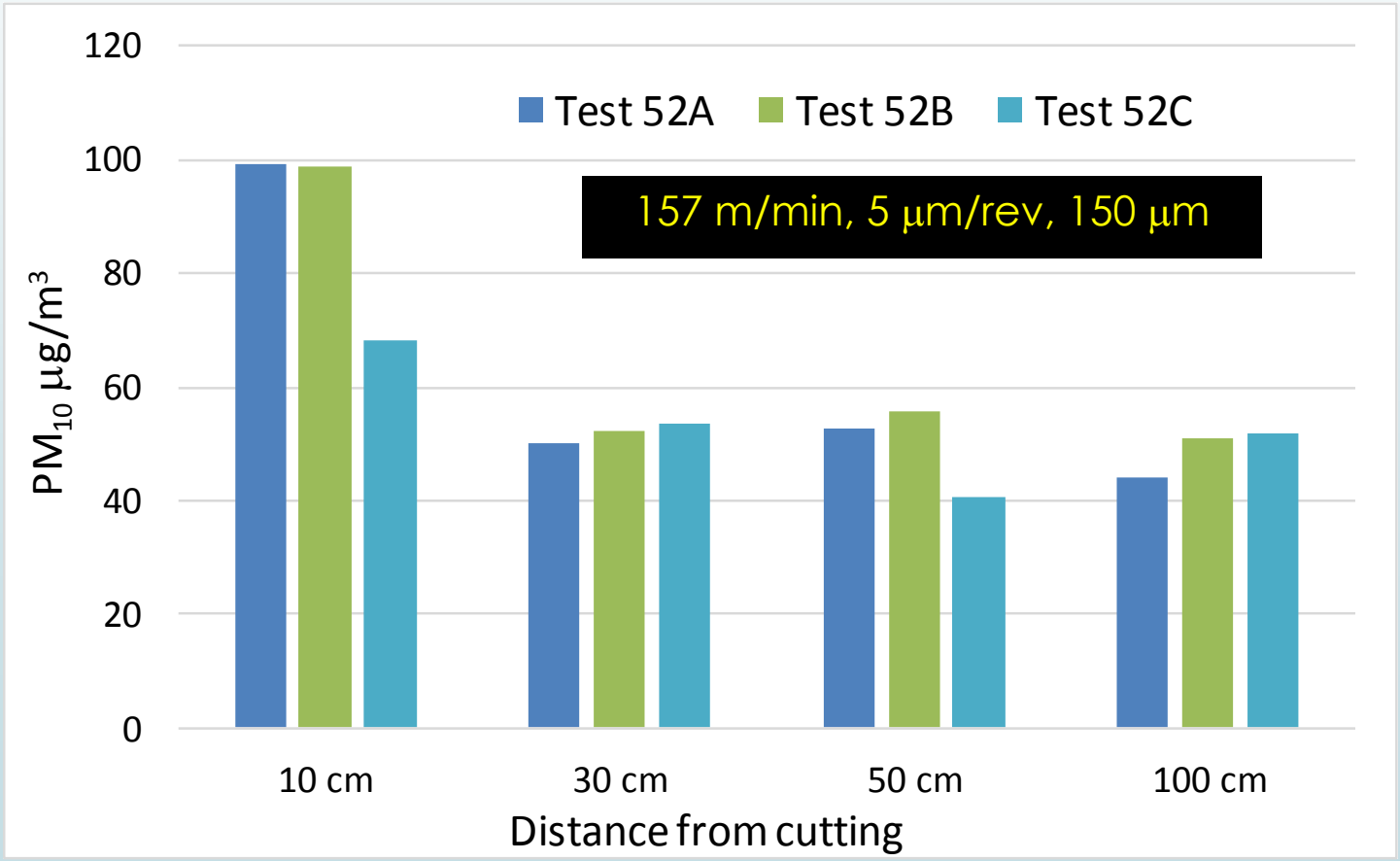
Effect of material on PM_{10} concentration

- Graphene/epoxy has in general higher concentration compared with clay/polyester



Repeatability of tests

- High repeatability of measurement with a maximum error 1.5% of the IOM WEL (i.e. 1000 μg/m^3)



Conclusions and Future Work

- Within the operating conditions tested, released particulate concentrations are well below the recommendation WEL for respirable dust.
- If IOM recommended limits are considered (1 mg/m^3), few conditions are above such limits indicating the potential risk.
- In the range of 50 cm away from the cutting zone, particulate concentrations are below recommended limits.

Conclusions and Future Work

- It is the PM10 fraction that is most closely associated with changes in cutting the parameters (i.e. compared to PM2.5 and PM1), suggesting that most dust produced is within this category (or higher, i.e. TSP).
- However, there is limited information on health hazards of nanoparticles (<0.1µm) and so, even though our study suggests low concentrations of this size fraction are generated, these concentrations may still be associated with significant health effects. Adequate precautions need to be taken.
- **The further work** will focus on characterising the specific nano particles that are produced, especially by scanning electron microscopy.